AD NUMBER
AD388041
CLASSIFICATION CHANGES
TO: **UNCLASSIFIED**
FROM: **CONFIDENTIAL**
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution: Further dissemination only as directed by U.S. Army Missile Command, Attn: AMSMI-IYC, Redstone Arsenal, AL 35809, SEP 1967, or higher DoD authority. This document contains export-controlled technical data.**
AUTHORITY
USAMICOM ltr dtd 1 Feb 1974 USAMICOM ltr dtd 1 Feb 1974

GENERAL DECLASSIFICATION SCHEDULE

IN ACCORDANCE WITH
DOD 5200.1-R & EXECUTIVE ORDER 11652

THIS DOCUMENT IS:

CLASSIFIED BY DDC

Subject to General Declassification Schedule of Executive Order 11652-Automatically Downgraded at 2 Years Intervals- DECLASSIFIED ON DECEMBER 31, 73.

BY

Defense Documentation Center
Defense Supply Agency
Cameron Station
Alexandria, Virginia 22314

SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked.
Separate page printouts MUST be marked accordingly.

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

CONFIDENTIAL

COPY [redacted]

A. D.

Technical Report S-146

HUGONIOT CURVES OF PROPELLANTS(U)

by

E. G. Johnson
M. L. Pandow

September 1967

U. S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

Contract DA-01-021 AMC-15414(Z)

ROHM AND HAAS COMPANY
REDSTONE RESEARCH LABORATORIES
HUNTSVILLE, ALABAMA 35807

DISTRIBUTION LIMITED
SEE INSIDE FRONT COVER

CONFIDENTIAL

DISTRIBUTION LIMITATION

Initial distribution of this report has been made in accordance with contractual agreements and approved supplements received from our Contracting Officer. Qualified users may obtain this report from the Defense Documentation Center, Cameron Station, Building 5, Alexandria, Virginia 22314.

In addition to security requirements which must be met, this document is subject to special export controls, and each transmittal to foreign governments or foreign nationals may be made only with prior approval of:

Department of Army
Headquarters, U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DISPOSITION INSTRUCTIONS

When this report is no longer needed, Department of the Army organizations will destroy it in accordance with the procedures given in AR 380-5. Navy and Air Force elements will destroy it in accordance with applicable directions. Department of Defense contractors will destroy the report according to the requirements of the Industrial Security Manual for Safeguarding Classified Information. All others will return the report to:

Department of Army
Headquarters, U. S. Army Missile Command
Redstone Arsenal, Alabama 35809
ATTN: AMSMI-IYC

DOWNGRADED AT 3 YEAR INTERVALS:
DECLASSIFIED AFTER 12 YEARS.

September 1967 Technical Report S-146

HUGONIOT CURVES OF PROPELLANTS(U)

by

E. G. Johnson
M. L. Pandow

U. S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

Contract DA-01-021 AMC-15414(Z)

ROHM AND HAAS COMPANY
REDSTONE RESEARCH LABORATORIES
HUNTSVILLE, ALAL . 4A 35807

(U) ABSTRACT

A microwave interferometry technique is used to determine shock velocities on both sides of a sample–Rohm and Haas' Plexiglas® interface. Particle velocities in the Plexiglas are determined from the known Hugoniot for Plexiglas. These particle velocities with the measured shock velocities are used in the impedance-mismatch equation to give the particle velocities in the sample. The shock pressure and specific-volume ratios in the sample are calculated for each shock velocity giving the Hugoniot parameters of the sample. Measurements were made on a propellant formulation, the same formulation with the oxidizer replaced by potassium chloride, and Owens-Corning's Fiberglas®. In the inert propellant it was found that the continuous phase (binder) has the largest influence on the pressure-specific-volume-ratio relation. The active propellant gave results considerably different from the inert propellant at pressures above 20 kbars, indicating that reaction of the oxidizer contributes energy to the shock front in a non-detonating system.

(C) FOREWORD

This work was performed under Contract DA-01-021 AMC-15414(Z) for propagation of stress waves in propellants under the cognizance of the Propulsion Mechanics Branch, Army Propulsion Laboratory and Center, Research and Development Directorate, U. S. Army Missile Command, and is in support of Defense Atomic Support Agency Nuclear Weapons Effects Research Subtask 15.045.

CONTENTS

Section I. INTRODUCTION

The work discussed in this report is a continuation of the experimental determination of Hugoniot curves of propellants and simulated propellants (1).[1] The work was initiated in an effort to determine the response of propellant to shock waves with the hope of being able to relate the information obtained to the initiation of detonation in these materials.

The Hugoniot equation expresses the energy change across the shock front. A common form is

$$e_1 - e_0 = \tfrac{1}{2}(p_0 + p_1)(\tau_0 - \tau_1) \qquad (1)$$

The Hugoniot can be expressed in terms of the shock velocity - particle velocity, the shock velocity-pressure, the pressure-volume, or any other two variables of state.

The two measurable variables are the shock velocity and the particle velocity. The shock velocity is measured directly and the particle velocity by an indirect technique. In this work, microwave interferometry is used to measure the shock velocity on both sides of a sample Plexiglas®[2] interface. The particle velocity in Plexiglas is determined from the known Hugoniot for Plexiglas (2). The particle velocity in the sample is then calculated using the impedance-mismatch equation,

$$\frac{u_i}{u_f} = \frac{\rho_f U_f + \rho_i U_i}{2\rho_i U_i} \qquad (2)$$

The shock velocity-particle velocity data can be converted into pressure-shock velocity and pressure-specific-volume ratio data through the following relations:

$$p = \rho_0 u U \qquad (3)$$

$$\frac{\tau}{\tau_0} = 1 - \frac{u}{U} \qquad (4)$$

---

[1] Numbers in parentheses in the text indicate references at the end of the report.

[2] Trademark of Rohm and Haas Company, Philadelphia, Pa.

The work described in reference (1) encompassed measurements on a polymeric base,[3] the polymeric base containing 20% aluminum, and two simulated propellants: the one contained ammonium perchlorate oxidizer and the other contained potassium chloride replacing the ammonium perchlorate by weight. There appeared to be significant differences between the two propellant-like formulations. These were interpreted as being caused by the energy released by reaction of ammonium perchlorate contributing to the forward motion of the shock front. However, extreme scatter in the data for the formulation containing active oxidizer precluded definite conclusions.

In the present work, improved experimental techniques have been used to eliminate much of the data scatter.

In addition to the propellant-like formulations, Hugoniot measurements were made on Fiberglas®[4]. This is a material typically used in rocket-motor cases, and it was hoped that the information obtained together with propellant data would give insight into the effect of shock waves, or other energetic stimuli of the same strength, on rocket motors.

---

[3]The polymeric base, P-13, was erroneously referred to in (1) as a methacrylate. It is a polyester-styrene formulation.

[4]The Fiberglas samples studied were received from Propulsion Laboratory with no specification as to the type of Fiberglas. Fiberglas is a trademark of the Owens-Corning Fiberglas Corporation, Toledo, Ohio.

Section II. EXPERIMENTAL

Two propellant-like formulations were studied (Table I). The composition of the active formulation is close in solids loading to propellants. The amount of potassium chloride in the inert formulation represents a volumetric replacement of the ammonium perchlorate in the active formulation. In the previous study, the replacement had been by weight per cent. It was felt that a volumetric replacement would give a better duplication of the physical state of the active formulation. It can be seen from Table I that the differences in composition between a weight replacement and a volumetric displacement are small and, therefore, it will be of interest to compare the two.

Table I. Formulations Used in Hugoniot Studies

	Active Formulation	Inert Formulation
KCl	---	63.6
NH_4ClO_4	62.5	---
Al	12.5	12.5
PBAA/ERL 2774	25.0	23.9

The instrumentation (Figure 1) was the same as that previously described (1) except microwave radiation in K_a band at 32.95 GHz and a high-pass filter between the crystal detector and the oscilloscope to attenuate the low-frequency signal from behind the shock front were used. The experimental setup is given in Figure 2. Shots were made with specimens of 4 × 4-inch square cross sections with lengths up to 2.5 inches at 0.5 inch increments interposed between a 2-inch-diameter by 6-inch-long pentolite booster and a Plexiglas block of 4 × 4 inch square cross section, 1 or 2 inches long.

The oscilloscope was triggered by the ionization probe approximately 1 inch from the base of the pentolite charge to record the detonation front in the last inch of the pentolite and the decay of the shock front through the specimen and the Plexiglas. Each cycle of the recorded signal on the oscillogram represents a displacement of the shock front by a half wave length of the microwaves in the sample. In a typical oscillogram for the active formulation (Figure 3) the detonation front in the explosive (A), the shock front in the specimens (B) and the shock front in the Plexiglas (C) can be seen. One-μsec time marks are shown at the base of the oscillogram in Figure 3. The displacement-time curves from the oscillogram in Figure 3 are shown in Figure 4. Velocity-distance curves calculated from the same oscillogram are shown in Figure 5.

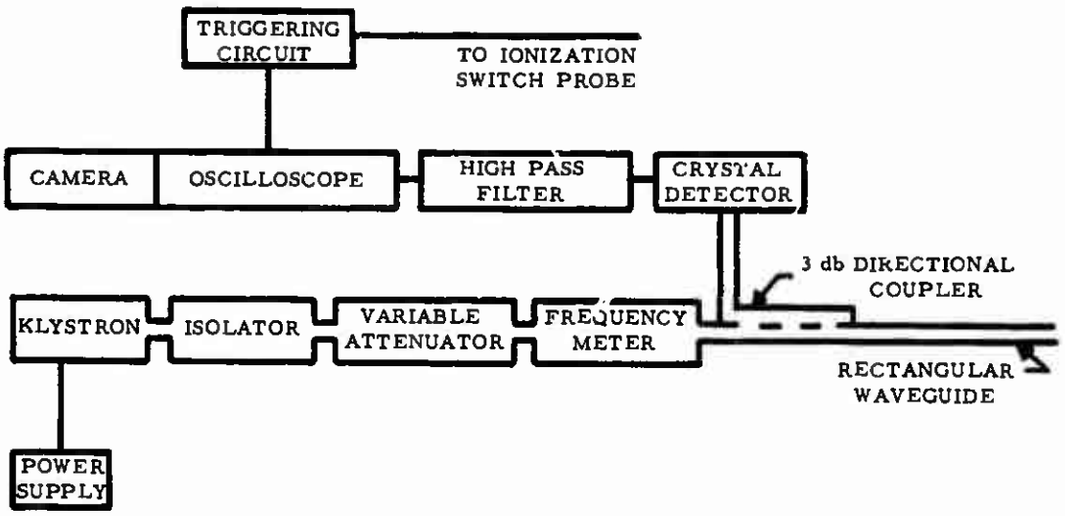

FIGURE 1. INSTRUMENTATION

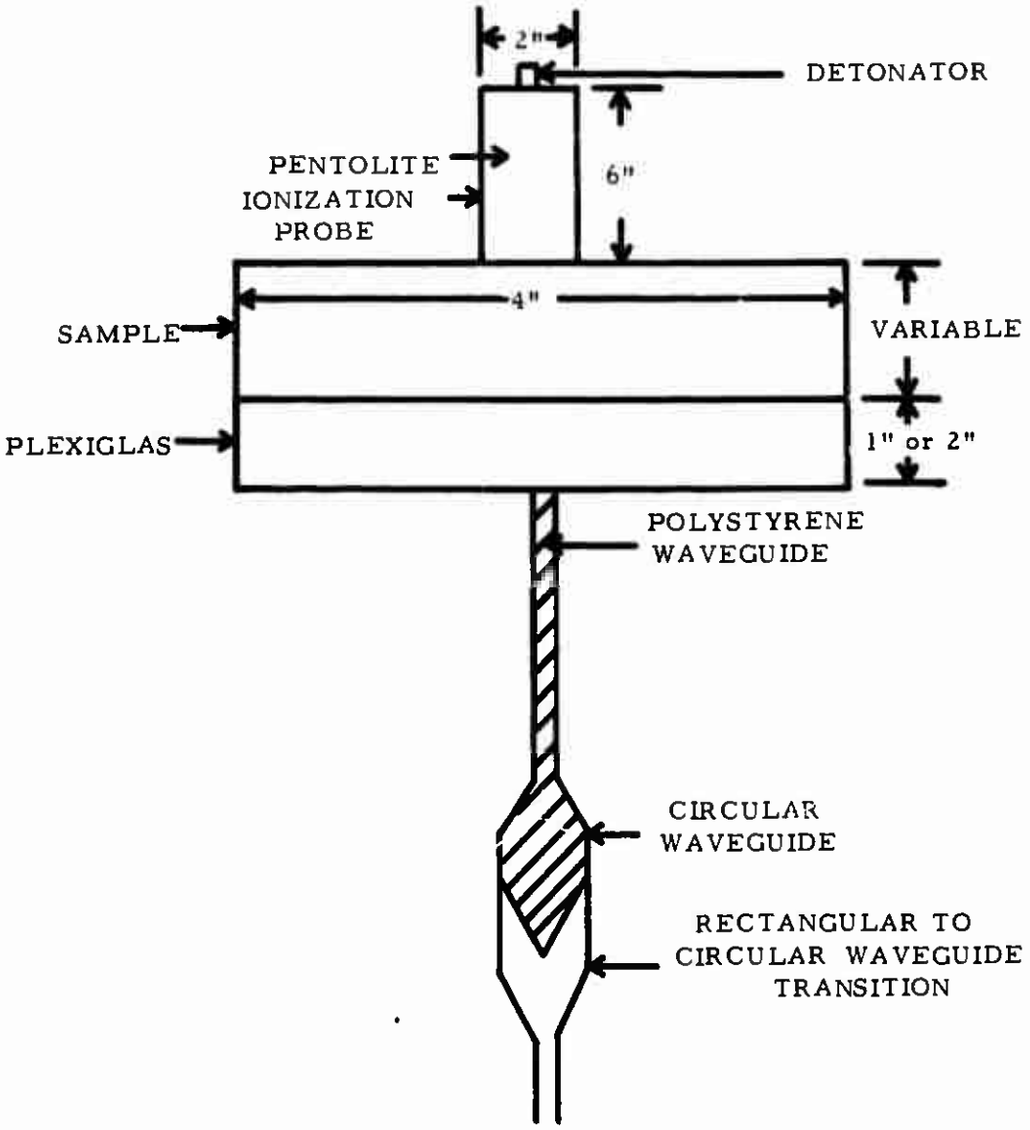

FIGURE 2. EXPERIMENTAL SET-UP

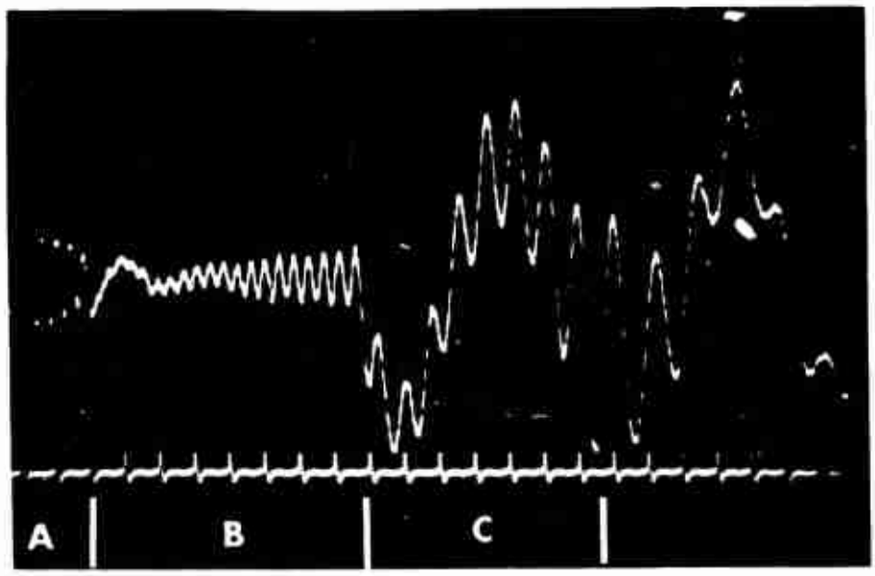

FIGURE 3. TYPICAL OSCILLOGRAM

The microwave wave length in the propellants and the Fiberglas was determined by counting the number of cycles on the oscillogram as the shock wave moved through a known thickness of specimen. Each cycle on the oscillogram corresponds to a half wave length in the propellant. For the inert propellant, three 2.00-inch samples were used. The number of half wave lengths observed were 25.0, 24.0, and 24.5 for an average of 2.07 ± 0.05 mm for a half wave length. For the active propellant, two nominally 2-inch and three nominally 1.5 inch samples were used. An average of 1.96 ± 0.05 mm for a half wave length was determined. For the Fiberglas, two nominally 2-inch and two nominally 1.5-inch samples were used. An average of 2.29 ± 0.05 mm for a half wave length was determined. All data were taken at a frequency of 32.95 GHz. The dielectric constant (3) for poly-methyl methacrylate is 2.65. At a frequency of 32.95 GHz a half wave length in the Plexiglas of 2.80 mm is calculated. The half wave lengths as determined by counting the number of cycles in the oscillogram for five nominally 2-inch Plexiglas samples were all within an error of ± 0.05 mm of the calculated value.

Data from the shots of the inert and the active propellant were curve-fitted by the computer to equations of the form,

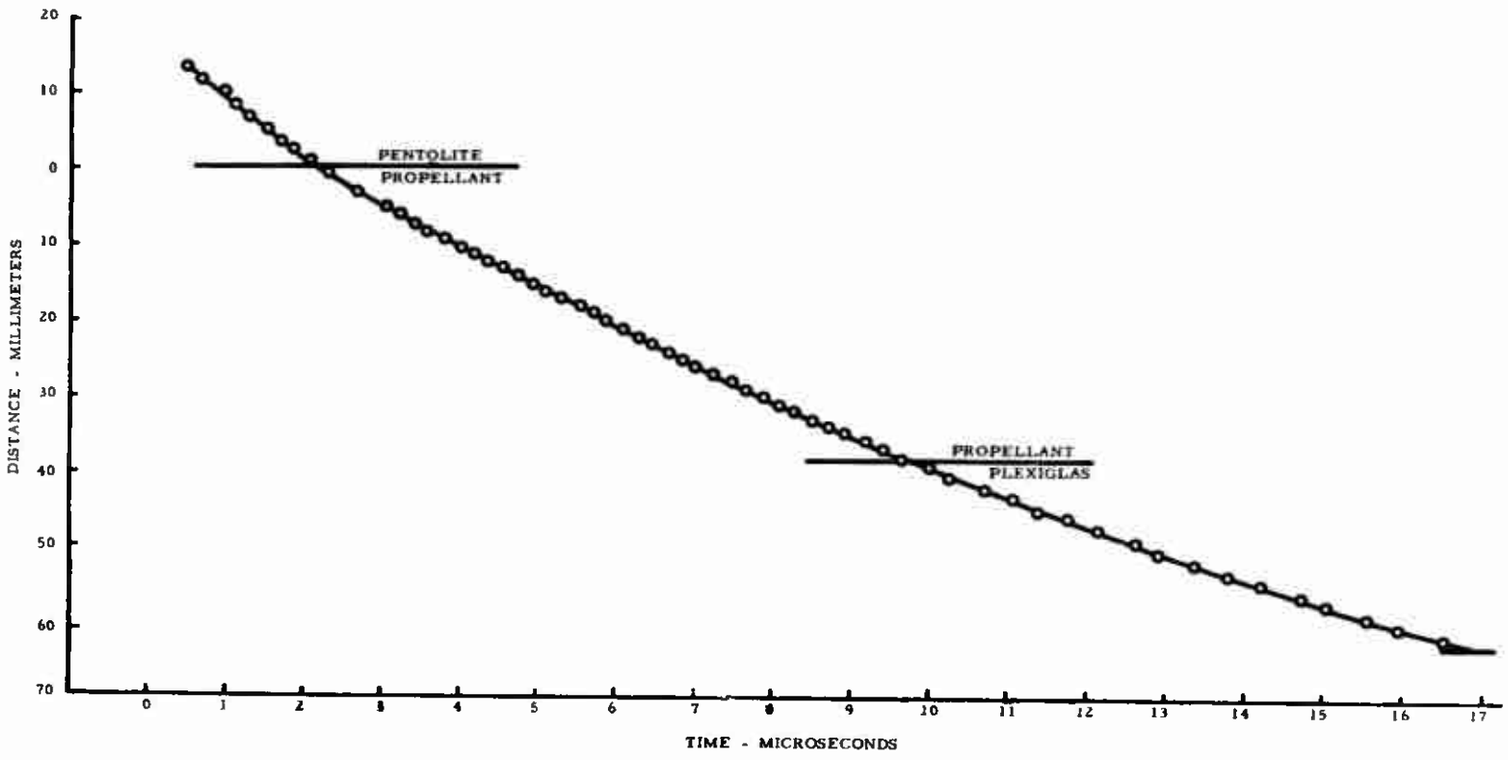

FIGURE 4. DISPLACEMENT-TIME CURVE FROM THE OSCILLOGRAM IN FIGURE 3

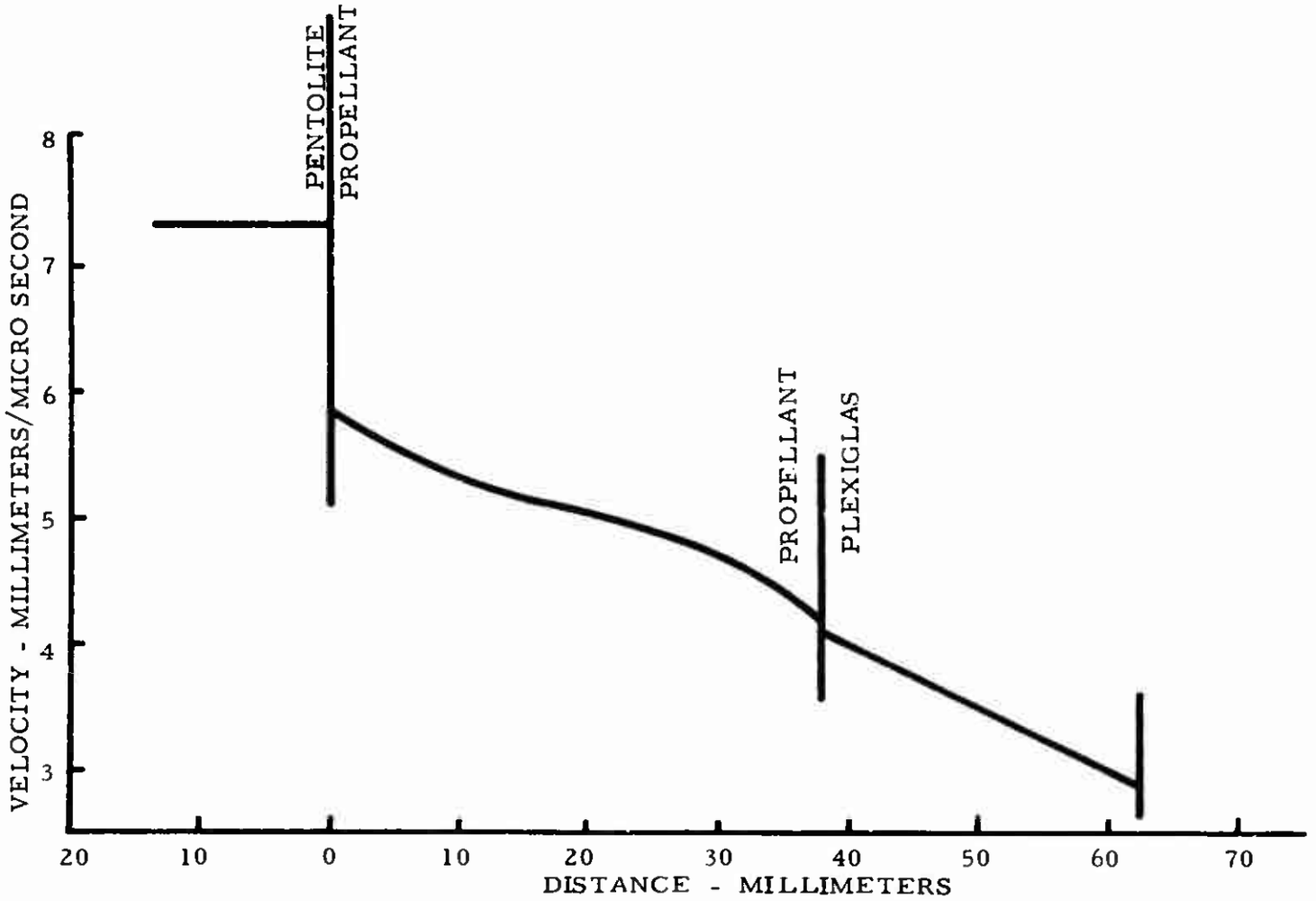

FIGURE 5. VELOCITY-DISTANCE CURVE FROM THE OSCILLOGRAM IN FIGURE 3

$$t = A + Bs + Cs^2 \cdots$$

and

$$t = e^{A + Bs + Cs^2 + \cdots}$$

where t is time in μsec and s is displacement in half wave lengths. Polynomials with degrees 1 through 5 were used depending on the number of data points and the amount of curvature. The function of ds/dt or the velocity was calculated and plotted as a function of s. The velocity at each interface was determined by linear extrapolation to the interface. Velocities, calculated from the slope of the straight line between data points, were also plotted with the calculated data for comparison. Tables II and III list the velocities determined in the above manner for these two propellants. Figure 6 shows the decay of the shock wave velocity in the inert propellant as a function of distance. Each trace is calculated from the curve fit of a single shot. Figure 7 shows the same results for the active propellant. Figure 8 compares the decay of the shock wave in the inert and the active propellants. Each curve is an average of the curves from the previous two figures.

Table II. Velocity Data from Inert Formulation

Shot No.	Propellant			Plexiglas		
	Length (inch)	Velocity In (mm/μsec)	Velocity Out (mm/μsec)	Length (inch)	Velocity In (mm/μsec)	Velocity Out (mm/μsec)
19	1/2	5.68	4.60	2	5.46	2.88
17	1/2	5.18	4.74	2	5.88	3.00
18	1/2	5.39	4.68	2	5.63	2.94
16	1	5.37	4.39	1	5.04	3.14
12	1	5.47	4.39	1	4.82	3.14
14	1	5.54	4.41	1	4.78	3.20
11	1 1/2	---	3.44	1	3.70	3.11
13	1 1/2	5.65	3.52	1	3.86	2.94
10	1 1/2	5.43	3.52	1	3.86	3.06
9	2	5.64	2.98	1	3.39	3.08
7	2	5.61	2.98	1	3.31	3.14
38	2 1/2	---	2.78	1	3.19	3.08
45	2 1/2	---	2.80	1	3.14	3.11

Table III. Velocity Data from Active Formulation

	Propellant			Plexiglas		
Shot No.	Length (inch)	Velocity In (mm/μsec)	Velocity Out (mm/μsec)	Length (inch)	Velocity In (mm/μsec)	Velocity Out (mm/μsec)
31	1/2	6.57	4.96	2	5.69	2.91
30	1/2	5.86	4.90	2	5.52	2.83
37	1	5.45	4.78	2	4.54	2.94
28	1	5.53	4.80	1	5.10	3.28
22	1	5.59	4.76	1	5.10	3.16
25	1 1/2	5.86	4.17	1	4.06	2.89
34	1 1/2	6.00	4.10	1	4.06	3.00
23	1 1/2	5.70	4.08	1	3.95	3.05
27	2	---	3.40	1	3.64	2.97
35	2	5.74	3.37	1	3.31	3.11
21	2	5.56	3.45	1	3.53	3.00
44	2 1/2	---	3.02	1	3.28	3.08

The data for Fiberglas had too much scatter to curve-fit, so velocities were determined graphically from the displacement-time data. The source of the scatter in the data was spurious changes in phase or amplitude of the reflected microwave radiation from the shock front. These changes in reflection may be associated with the laminated properties of the Fiberglas although the dimensions of the layers are small compared to a wave length of the microwave. Different sample lengths were made by stacking 0.3 in. sheets of Fiberglas which introduced additional interfaces. However, the same type of results was obtained when the sheets of Fiberglas were held together by an epoxy similar to the one used in making the Fiberglas. Table IV lists the velocities determined graphically for Fiberglas. The velocities from the Fiberglas determined graphically for shots 48 and 42 were so far out of line with the other data that data from shots 49 and 50 were used to determine the velocities listed in Table IV.

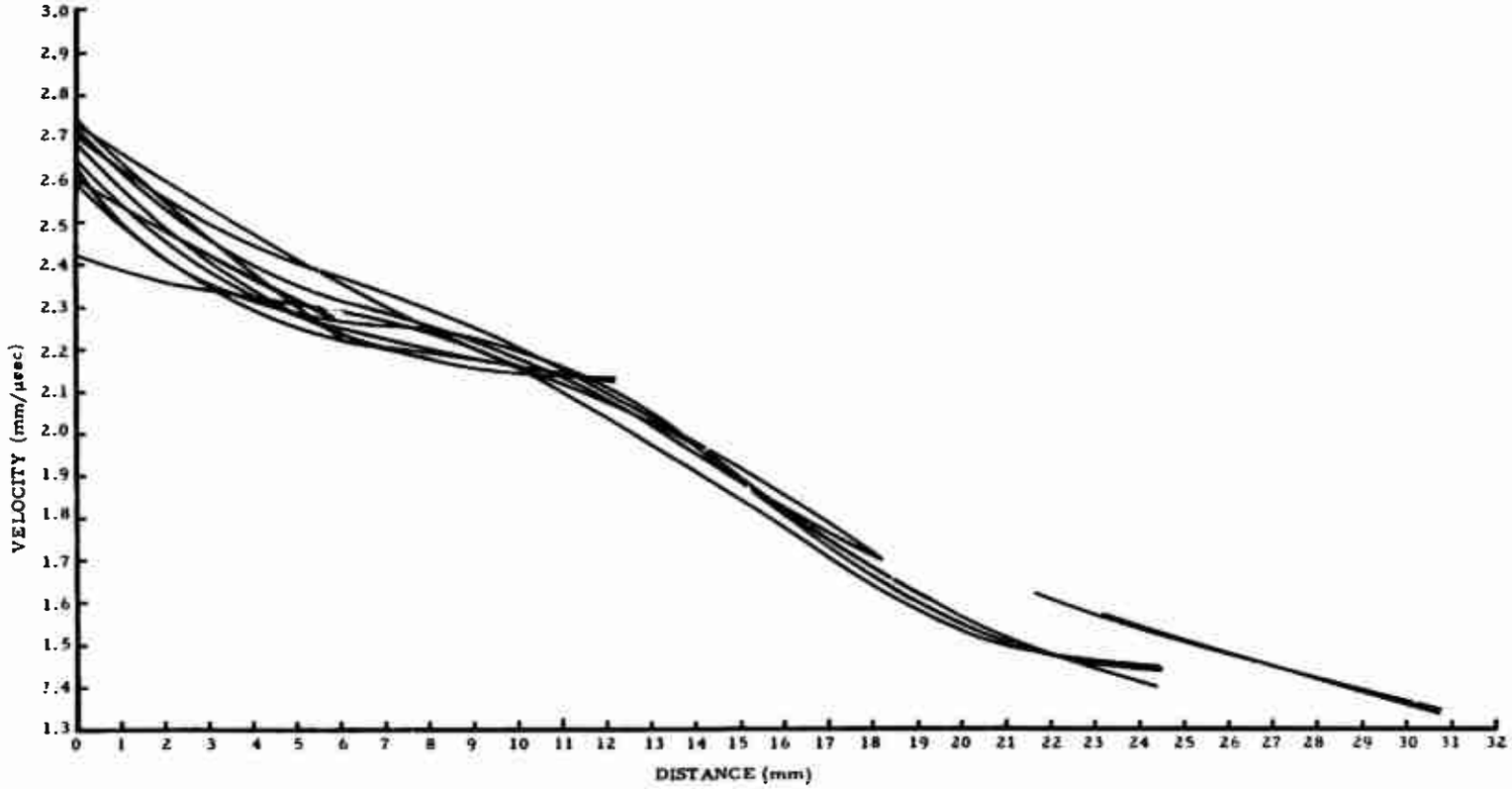

FIGURE 6. DECAY OF THE SHOCK VELOCITY AS A FUNCTION OF DISTANCE IN THE INERT PROPELLANT

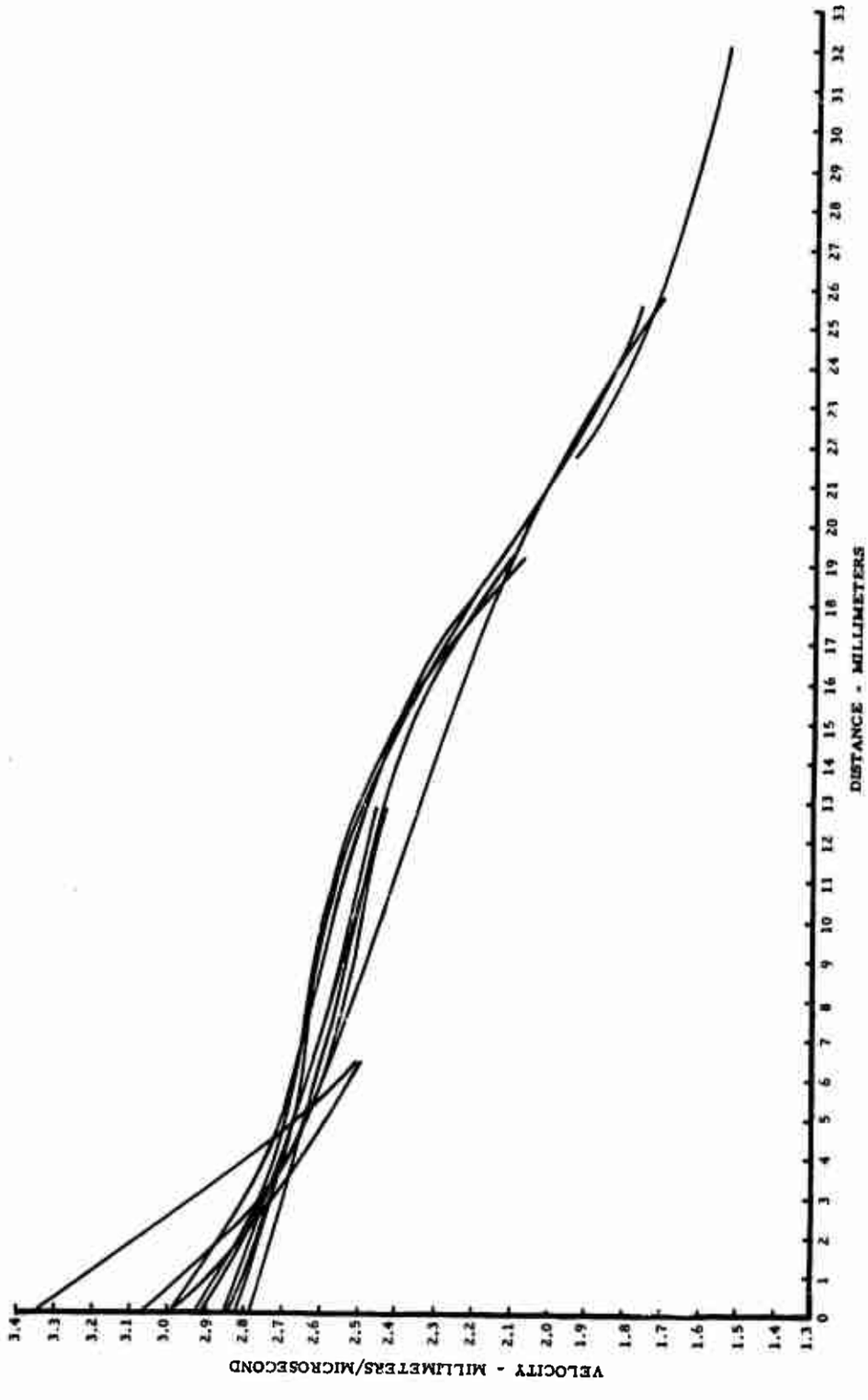

FIGURE 7. DECAY OF THE SHOCK VELOCITY AS A FUNCTION OF DISTANCE IN THE ACTIVE PROPELLANT

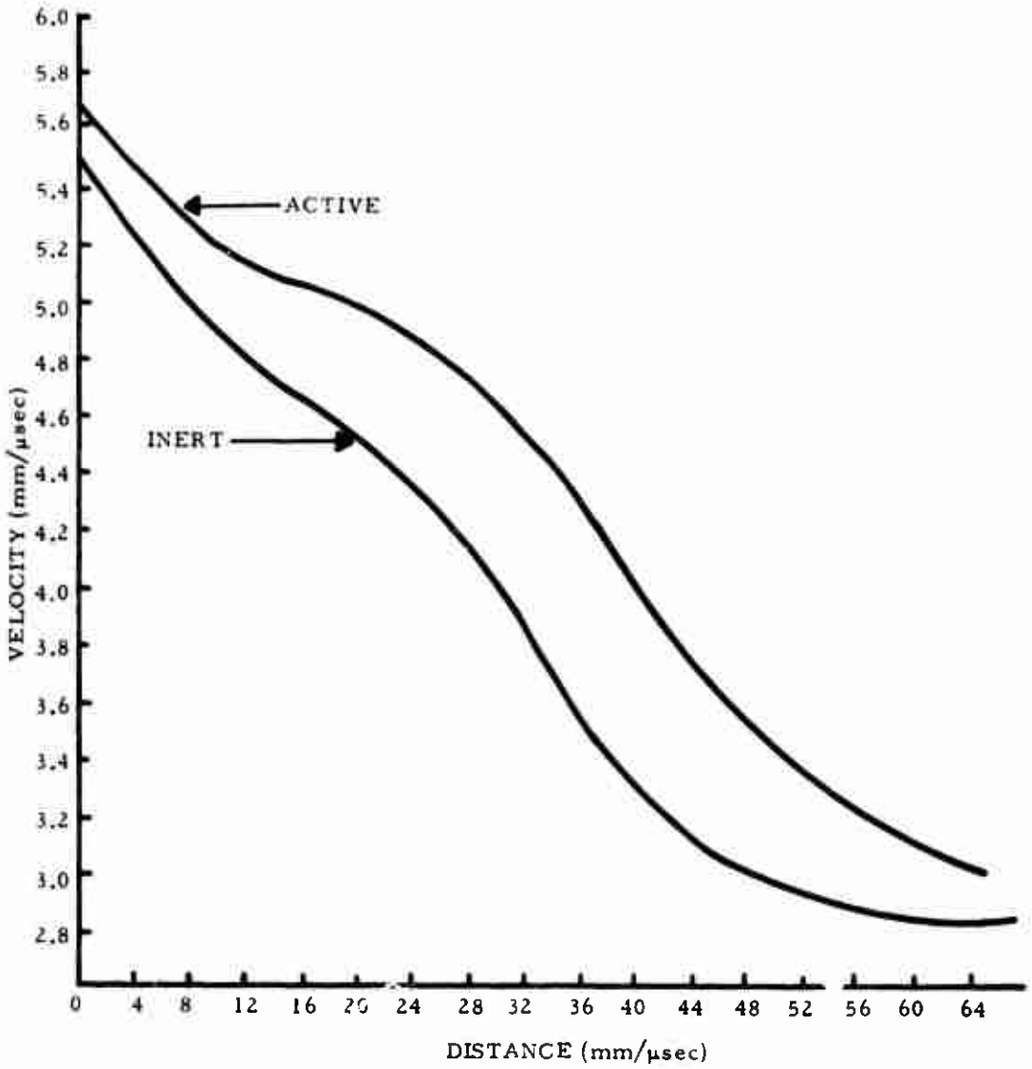

FIGURE 8. COMPARISON OF THE DECAY OF THE SHOCK VELOCITY AS A FUNCTION OF DISTANCE FOR INERT AND ACTIVE PROPELLANT

Table IV. Velocity Data from Fiberglas

Shot No.	Fiberglas			Plexiglas
	Length (inch)	Velocity In (mm/μsec)	Velocity Out (mm/μsec)	Velocity In (mm/μsec)
46	0.295	4.35	4.35	5.65
41	0.330	4.76	3.95	5.08
20	0.990	4.90	3.05	4.44
40	0.994	4.90	3.69	4.46
26	1.025	4.44	3.25	4.59
48	1.495	4.46	2.79[a]	3.44
42	1.482	4.72	2.79[a]	3.73
49	2.096	4.29	1.92	3.13
50	2.095	4.49	2.08	3.12

[a]Obtained from data on shots 49 and 50.

Section III. RESULTS

Particle velocities in the Plexiglas were determined from the measured shock velocity and the Hugoniot for Plexiglas given by Naval Ordnance Laboratory in Ref. 2. This report gives shock velocity-particle velocity data obtained at NOL and states that these data are more precise than data previously obtained. However, in calibrating the "standard card gap test," the authors use the equation

$$U = 2.588 + 1.514u \qquad (5)$$

This differs significantly from the data reported in Table IV of Ref. 2 (Figure 9 of the present report) but agrees with earlier data cited therein. In general, the data tabulated in Table IV of Ref. 2 have been used in the calculations in the present work. In some cases, Eq. (5) has been used to show how the Hugoniot chosen for Plexiglas can affect the values calculated for the sample. Many experimentally determined curves are available for the Hugoniot of Plexiglas (4) and, since in many cases there is little apparent reason for selecting one of them, it is necessary that a particular curve be used in all cases where comparisons are to be made.

The values of the measured shock-velocities and derived particle velocities on both sides of the sample-Plexiglas interface, as well as the pressures and specific volume ratios, are given in Tables V, VI, and VII for the active formulation, the inert formulation and Fiberglas, respectively. The values were calculated using the data from Table IV, Ref. 2, as the Hugoniot for Plexiglas. Table VIII gives data calculated for the inert formulation using Eq. (5) as the Hugoniot for Plexiglas.

The values for the active and inert compositions are compared in shock velocity-particle velocity, pressure-shock velocity, and pressure-specific volume ratio curves in Figures 10, 11, and 12, respectively. Values for the inert formulation calculated using the tabulated data from Ref. 2 for the Hugoniot of Plexiglas and those calculated using Eq. (5) are shown in Figures 13, 14, and 15. It is seen that different results are obtained. For comparison purposes, the tabular data of Table IV, Ref. 2 were used.

The Fiberglas data are compared with Plexiglas data from Ref. 2 in Figures 16, 17, and 18. Although the Fiberglas data scatter considerably, there is a significant difference between these data and those for Plexiglas.

Table V. Hugoniot Parameters for the Active Propellant Formulations

U_{plex} (mm/μsec)	u_{plex} (mm/μsec)	U_{prop} (mm/μsec)	u_{prop} (mm/μsec)	P (Kbars)	τ/τ_0
5.69	1.86	4.96	1.73	136	0.651
5.52	1.75	4.90	1.61	125	0.671
4.54	1.17	4.78	1.00	76	0.791
5.10	1.50	4.80	1.34	102	0.721
5.10	1.50	4.76	1.35	102	0.716
4.06	0.88	4.17	0.76	50	0.818
4.06	0.88	4.10	0.76	49	0.815
3.95	0.82	4.08	0.71	46	0.826
3.64	0.64	3.40	0.58	31	0.829
3.31	0.40	3.37	0.35	19	0.896
3.53	0.57	3.45	0.50	27	0.858
3.28	0.37	3.02	0.33	16	0.891

Table VI. Hugoniot Parameters for the Inert Propellant Formulation

U_{plex} (mm/μsec)	u_{plex} (mm/μsec)	U_{prop} (mm/μsec)	u_{prop} (mm/μsec)	P (Kbars)	τ/τ_0
5.46	1.72	4.60	1.62	118	0.648
5.88	1.97	4.74	1.90	143	0.599
5.63	1.82	4.68	1.73	128	0.630
5.04	1.47	4.39	1.36	95	0.690
4.82	1.34	4.39	1.22	85	0.722
4.78	1.31	4.41	1.18	82	0.732
3.70	0.67	3.44	0.60	33	0.826
3.86	0.77	3.52	0.70	39	0.801
3.86	0.77	3.52	0.70	39	0.801
3.39	0.47	2.98	0.43	20	0.856
3.31	0.40	2.90	0.37	17	0.872
3.19	0.27	2.78	0.25	11	0.910
3.14	0.20	2.80	0.18	8	0.936

Table VII. Hugoniot Parameters for Fiberglas

U_{plex} (mm/μsec)	u_{plex} (mm/μsec)	U_{Fib} (mm/μsec)	u_{Fib} (mm/μsec)	P (Kbars)	τ/τ_0
5.65	1.84	4.35	1.69	135	0.611
5.08	1.49	3.95	1.36	99	0.656
4.44	1.11	3.05	1.07	60	0.649
4.46	1.12	3.69	0.99	67	0.732
4.59	1.20	3.25	1.14	68	0.649
3.44	0.52	2.79	0.47	24	0.832
3.73	0.69	2.79	0.64	33	0.771
3.13	0.19	1.92	0.19	7	0.901
3.12	0.18	2.08	0.18	7	0.913

Table VIII. Hugoniot Parameters for the Inert Formulation Calculated Using Eq. (5) as the Hugoniot for Plexiglas

U_{plex} (mm/μsec)	u_{plex} (mm/μsec)	U_{prop} (mm/μsec)	u_{prop} (mm/μsec)	P (Kbars)	τ/τ_0
5.46	1.90	4.60	1.79	130	0.611
5.88	2.17	4.74	2.09	157	0.559
5.63	2.01	4.68	1.91	142	0.592
5.04	1.62	4.39	1.50	104	0.658
4.82	1.47	4.39	1.34	93	0.695
4.78	1.45	4.41	1.31	91	0.703
3.70	0.73	3.44	0.66	36	0.808
3.86	0.84	3.52	0.76	42	0.784
3.86	0.84	3.52	0.76	42	0.784
3.39	0.53	2.98	0.49	23	0.836
3.31	0.48	2.90	0.44	20	0.848
3.19	0.40	2.78	0.37	16	0.867
3.14	0.36	2.[illegible]	0.33	15	0.882

Shock velocity-particle velocity and pressure-specific volume ratio data for the inert formulation are compared with those of Plexiglas in Figures 19 and 20. While the shock velocity-particle velocity curves are very different, the pressure-specific volume ratio curves are surprisingly similar. This does, however, agree with results obtained in Ref. 1. The shock velocity-particle velocity curves obtained in this work and those from Ref. 1 are compared in Figure 21. Except at the highest values, the agreement is gratifyingly good. That the new experimental techniques have helped to eliminate much of the scatter can also be seen in this figure.

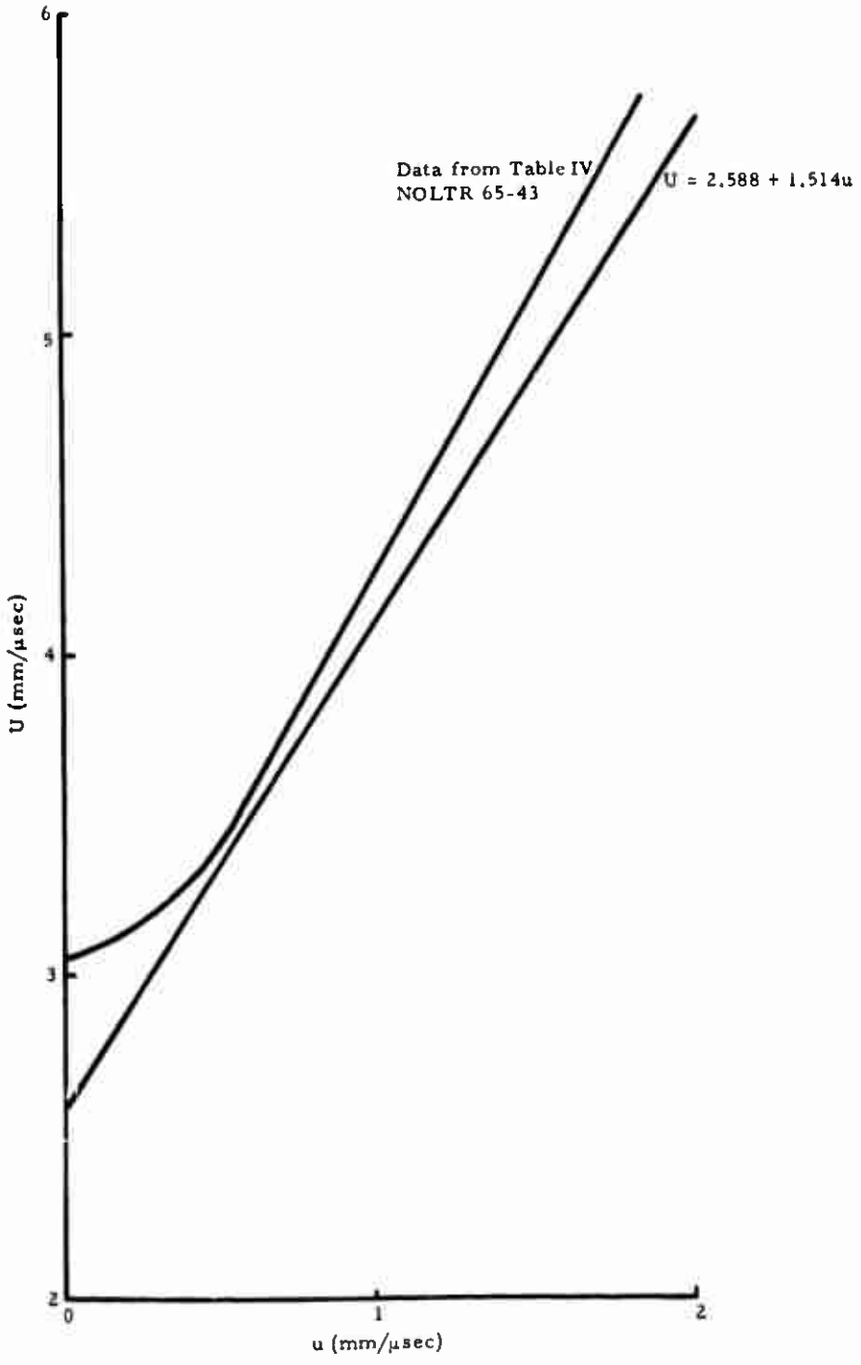

FIGURE 9. HUGONIOTS FOR PLEXIGLAS

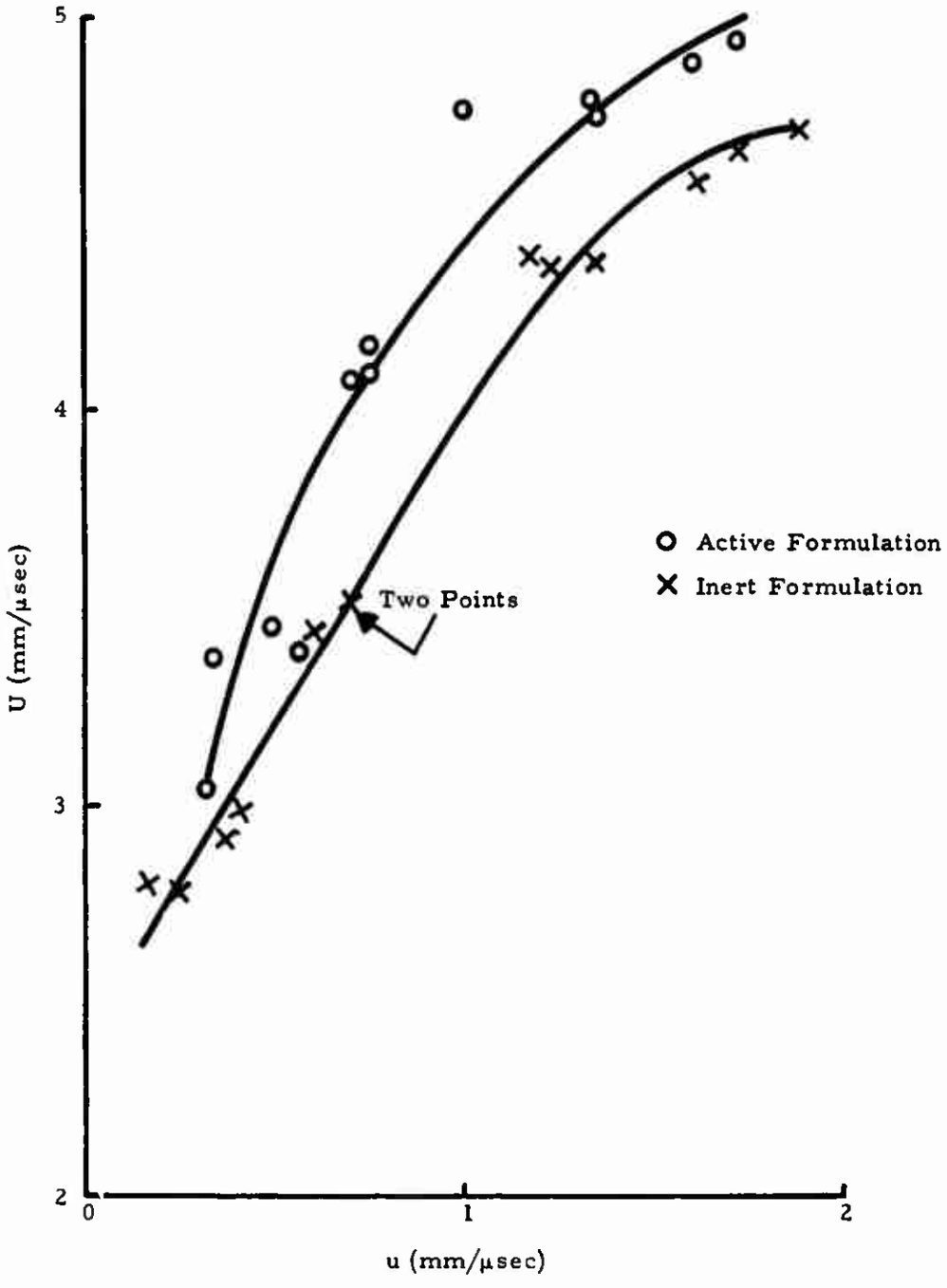

FIGURE 10. SHOCK VELOCITY VS. PARTICLE VELOCITY FOR ACTIVE AND INERT FORMULATIONS

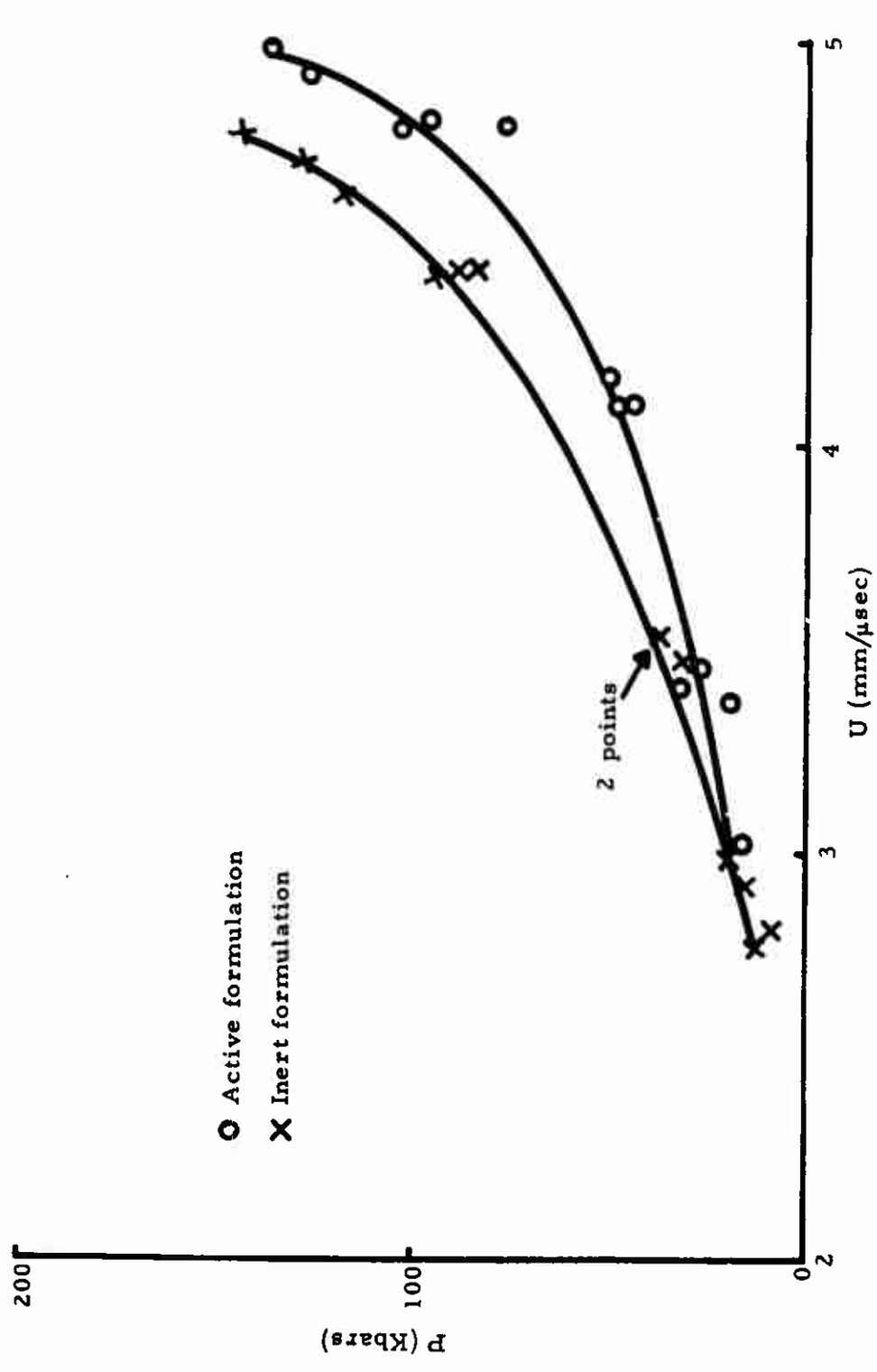

FIGURE 11. PRESSURE VS. SHOCK VELOCITY FOR ACTIVE AND INERT PROPELLANT FORMULATIONS

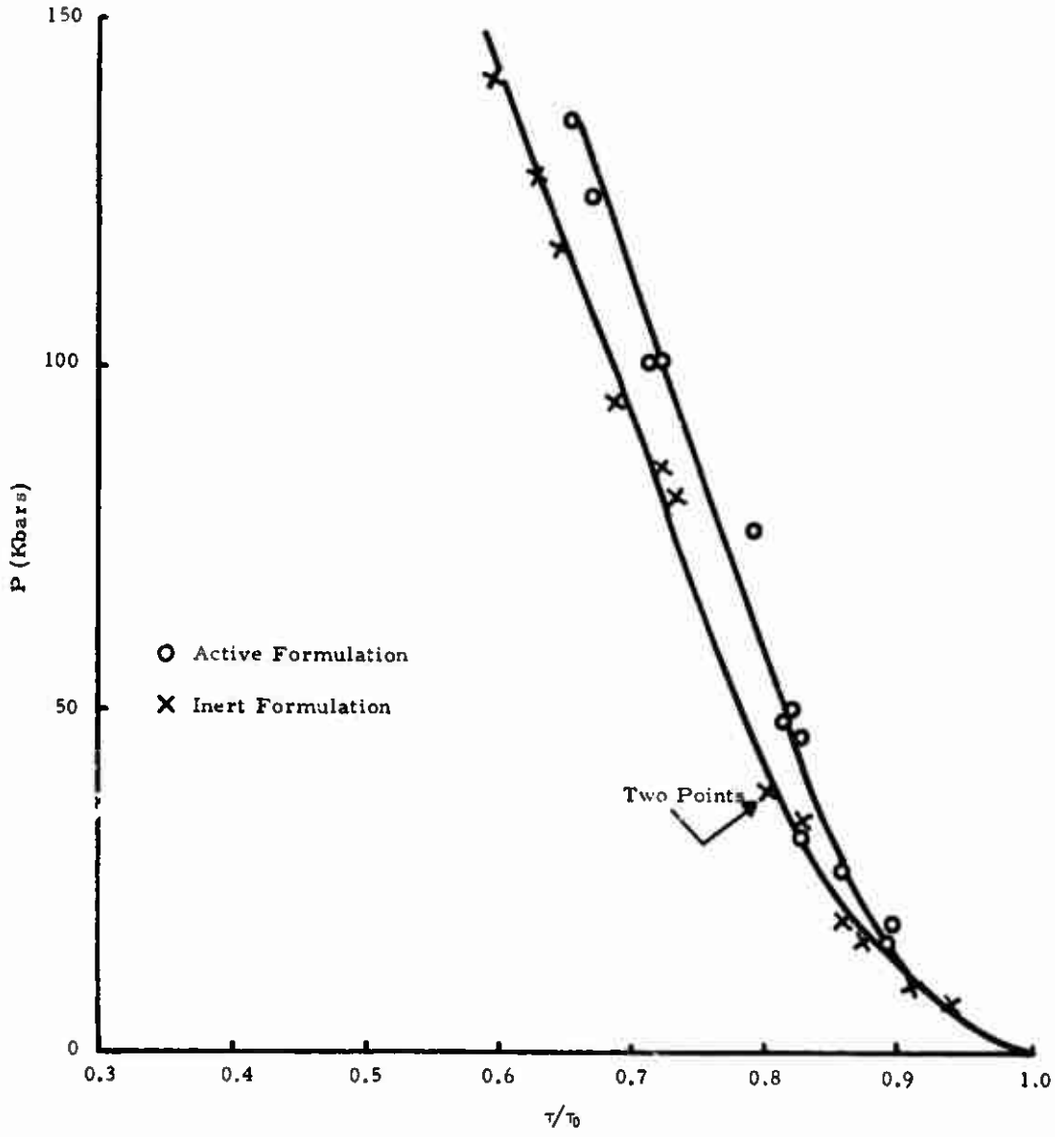

FIGURE 12. PRESSURE VS. SPECIFIC VOLUME RATIO FOR ACTIVE AND INERT PROPELLANT FORMULATIONS

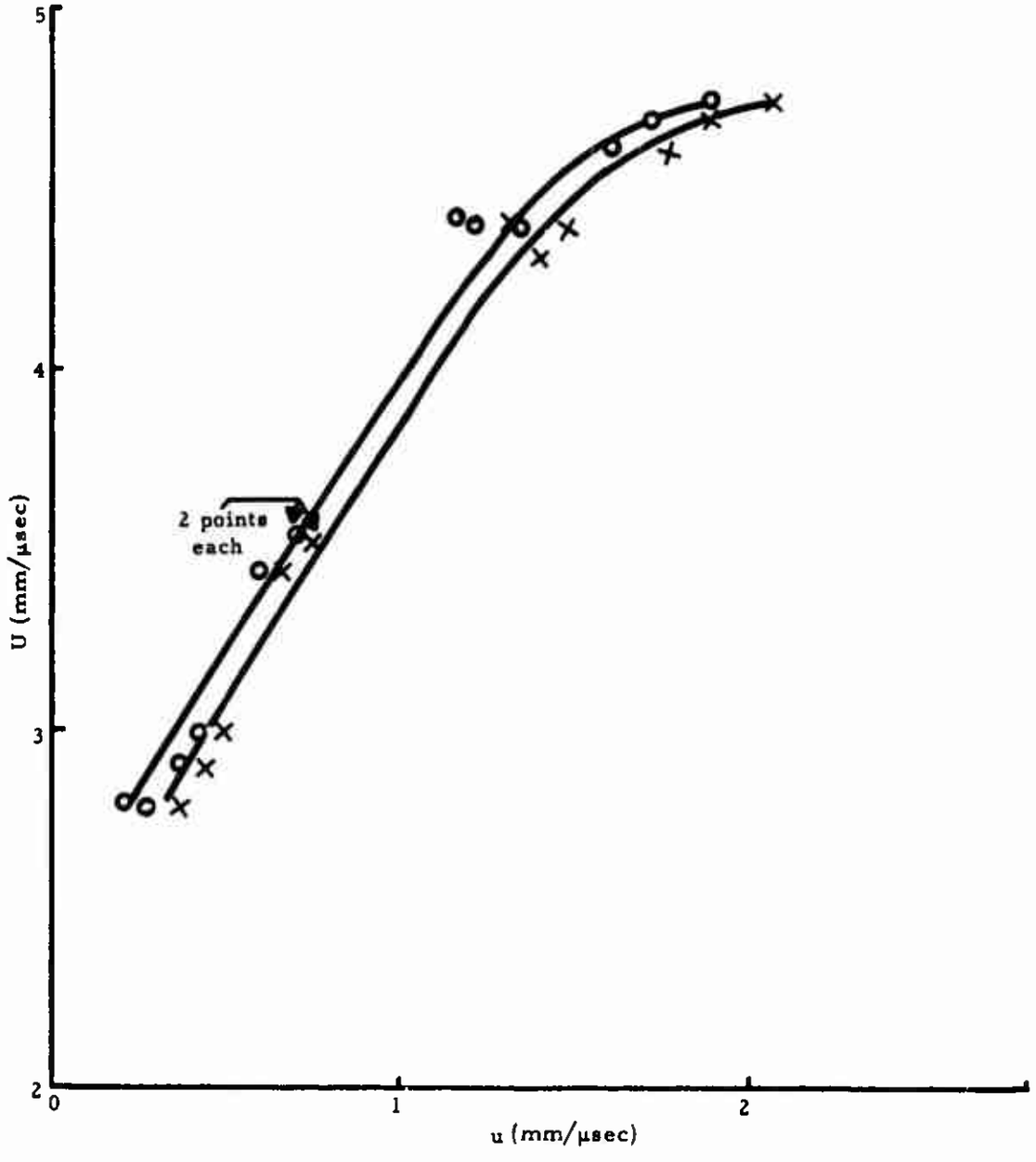

FIGURE 13. SHOCK VELOCITY VS. PARTICLE VELOCITY FOR THE INERT FORMULATION CALCULATED USING TWO DIFFERENT HUGONIOTS FOR PLEXIGLAS

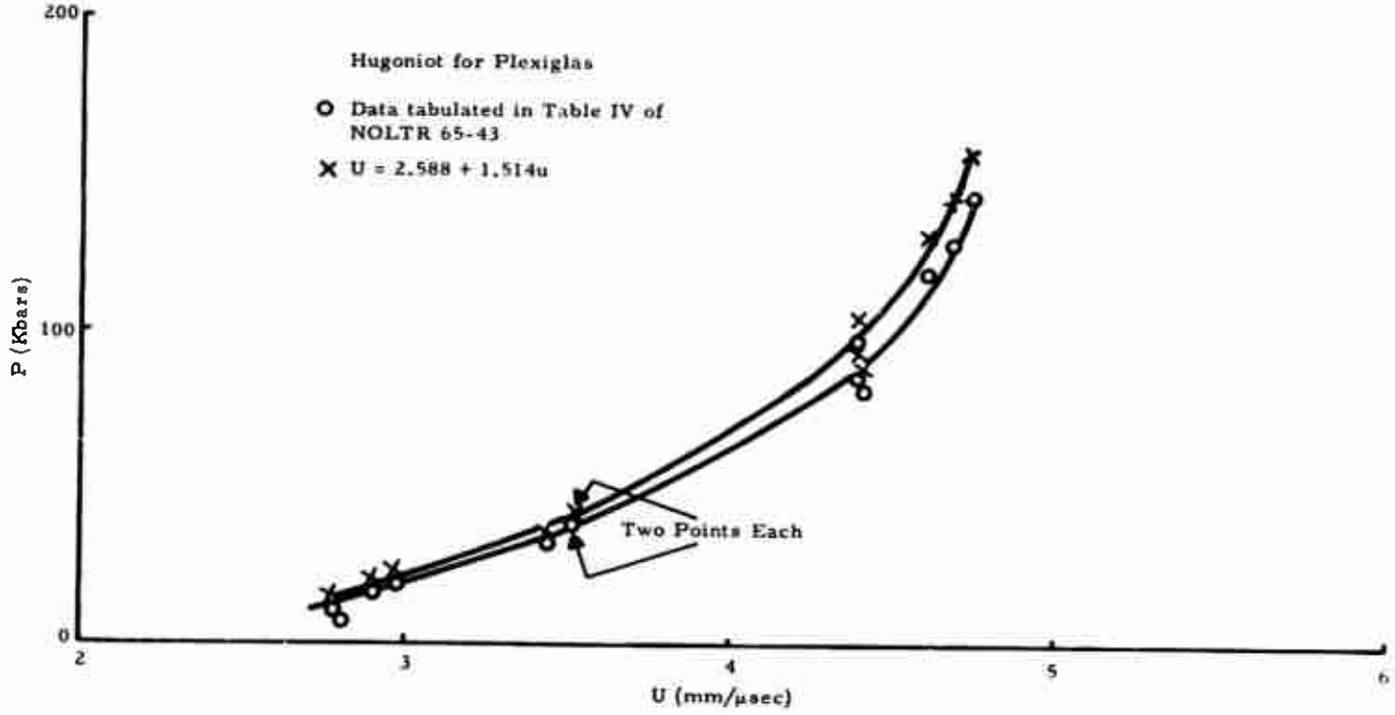

FIGURE 14. PRESSURE–SHOCK VELOCITY DA... FOR INERT FORMULATION CALCULATED USING TWO DIFFERENT HUGONIOTS FOR PLEXIGLAS

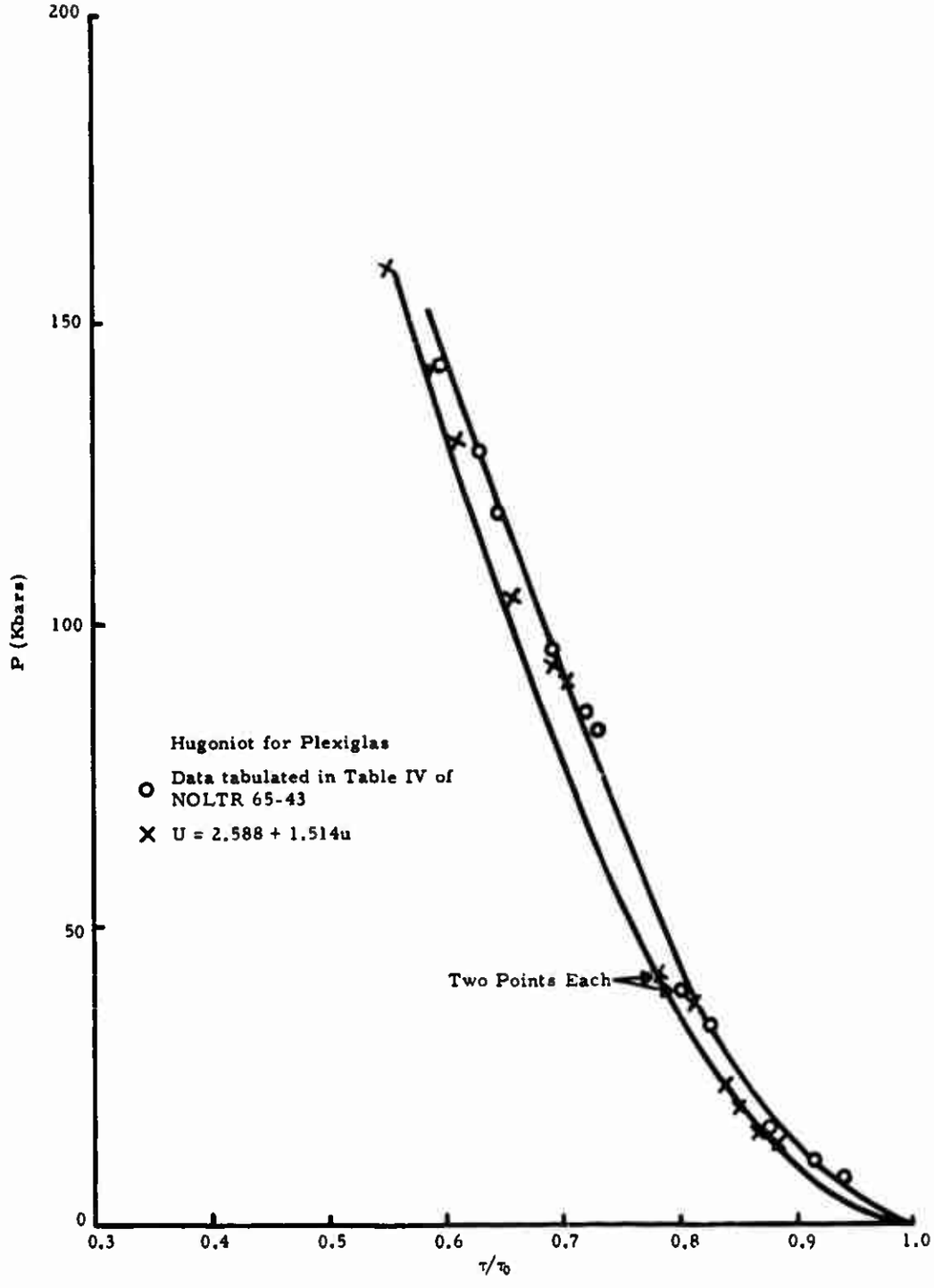

FIGURE 15. PRESSURE VS. SPECIFIC-VOLUME RATIO CALCULATED FOR INERT FORMULATION USING TWO DIFFERENT HUGONIOTS FOR PLEXIGLAS

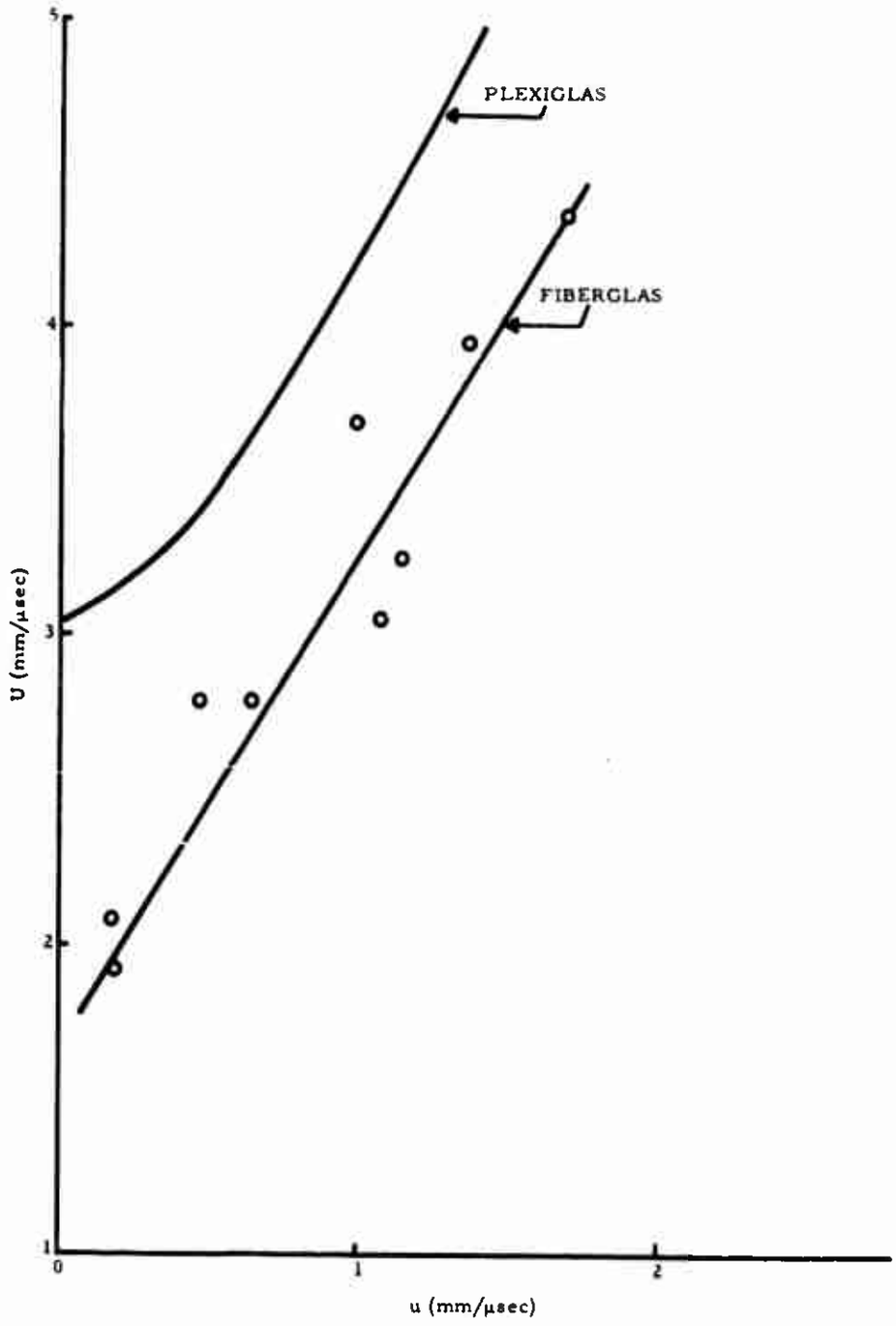

FIGURE 16. COMPARISON OF SHOCK VELOCITY VS. PARTICLE VELOCITY FOR FIBERGLAS AND PLEXIGLAS

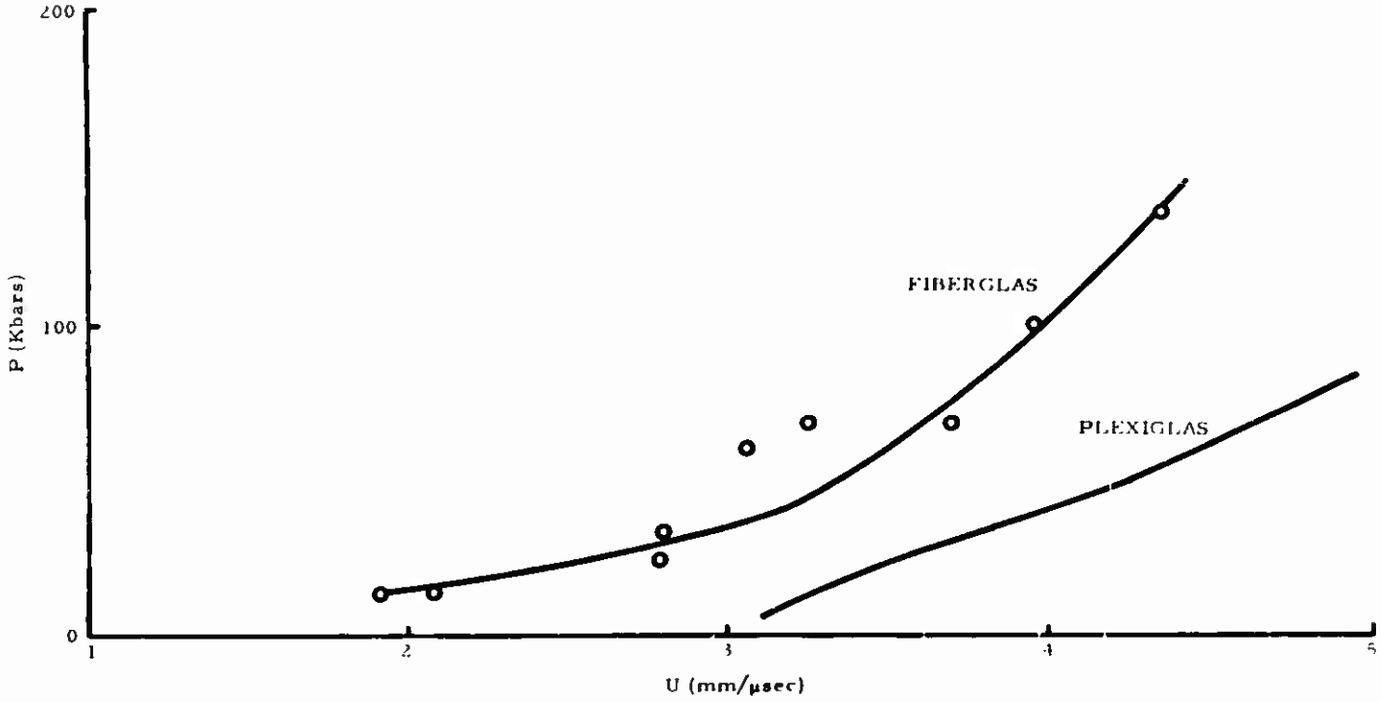

FIGURE 17. COMPARISON OF PRESSURE VS. SHOCK VELOCITY FOR FIBERGLAS AND PLEXIGLAS

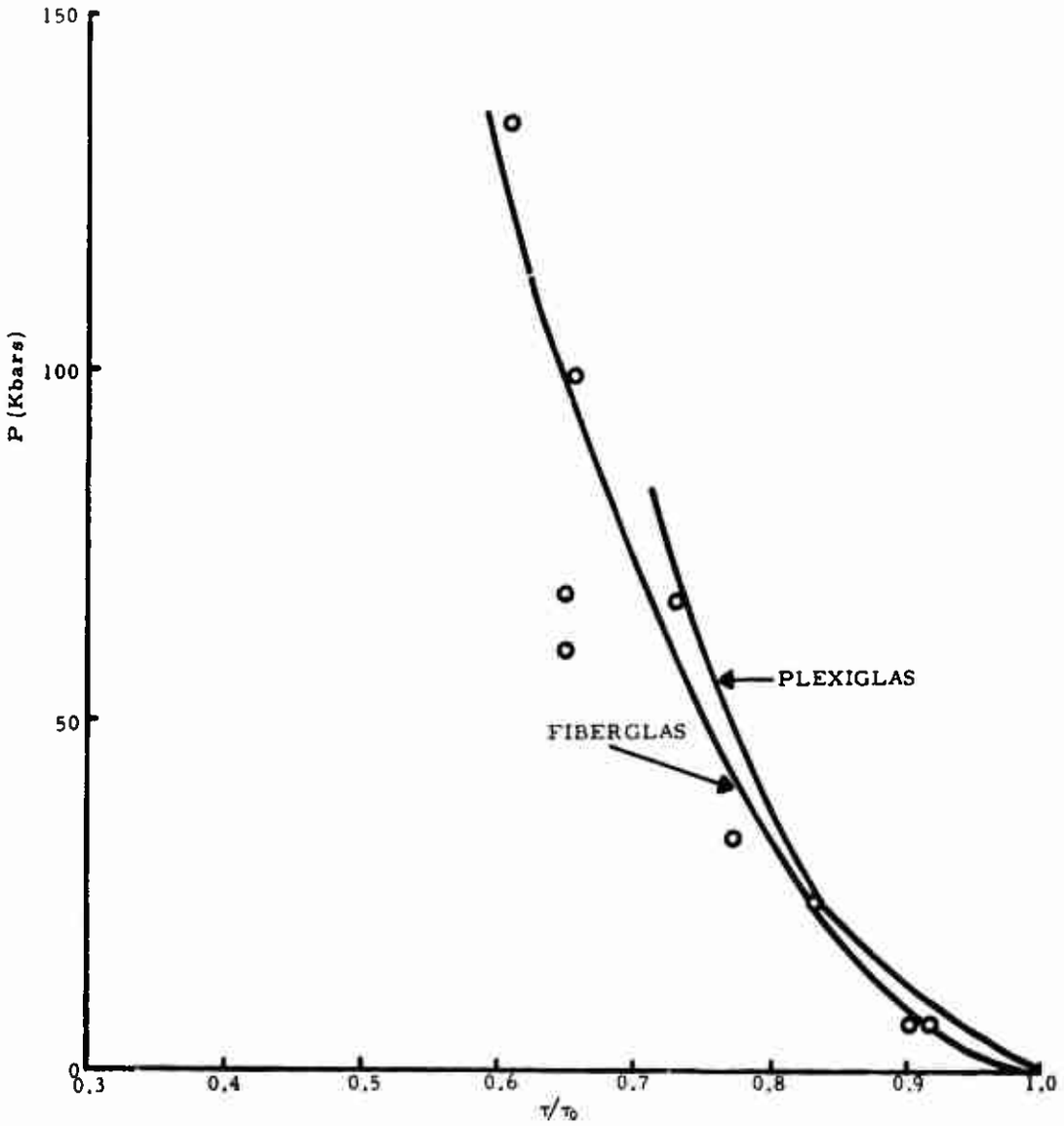

FIGURE 18. COMPARISON OF PRESSURE VS. SPECIFIC-VOLUME RATIO FOR FIBERGLAS AND PLEXIGLAS

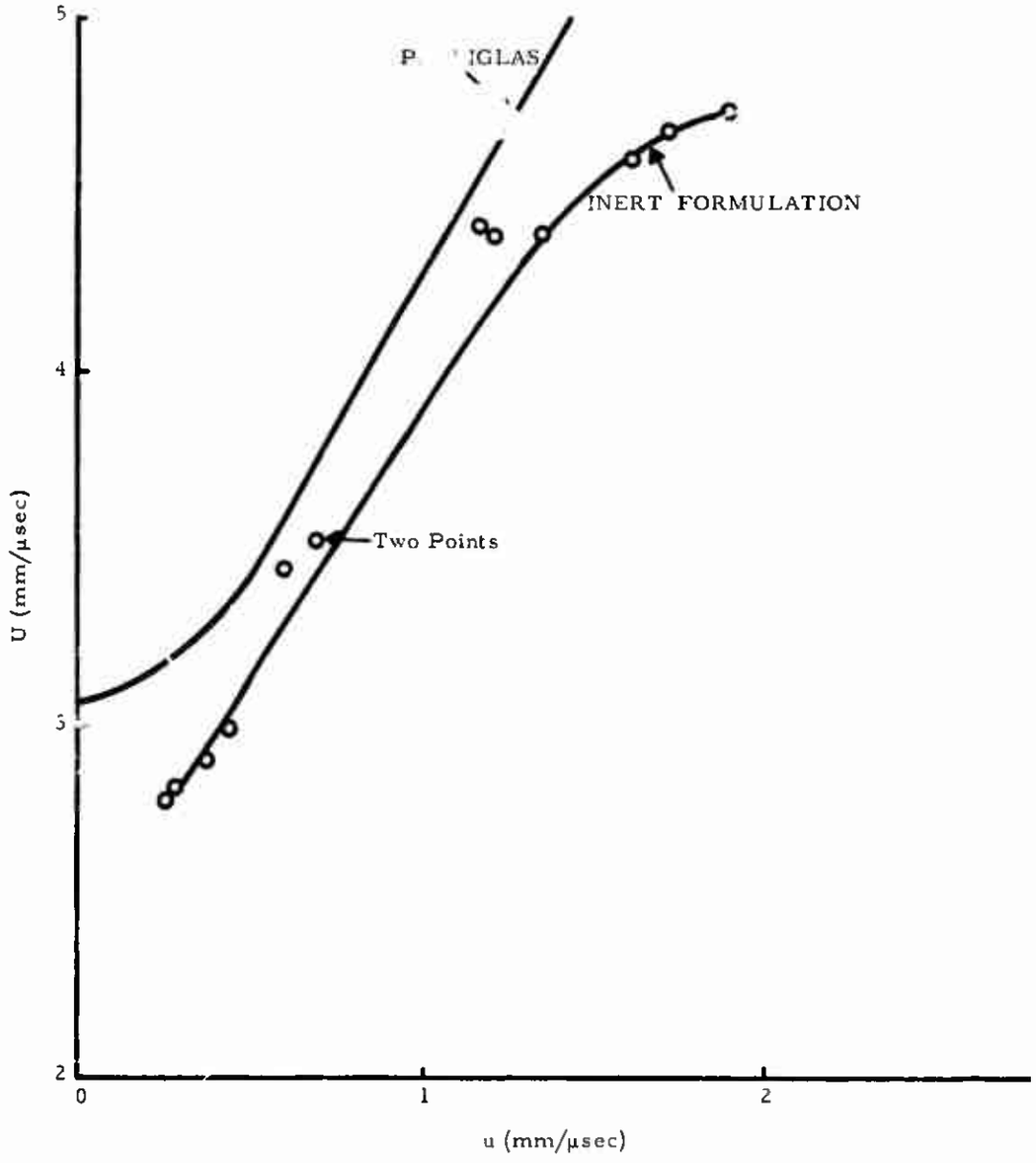

FIGURE 19. COMPARISON OF SHOCK VELOCITY VS. PARTICLE VELOCITY FOR INERT FORMULATION AND PLEXIGLAS

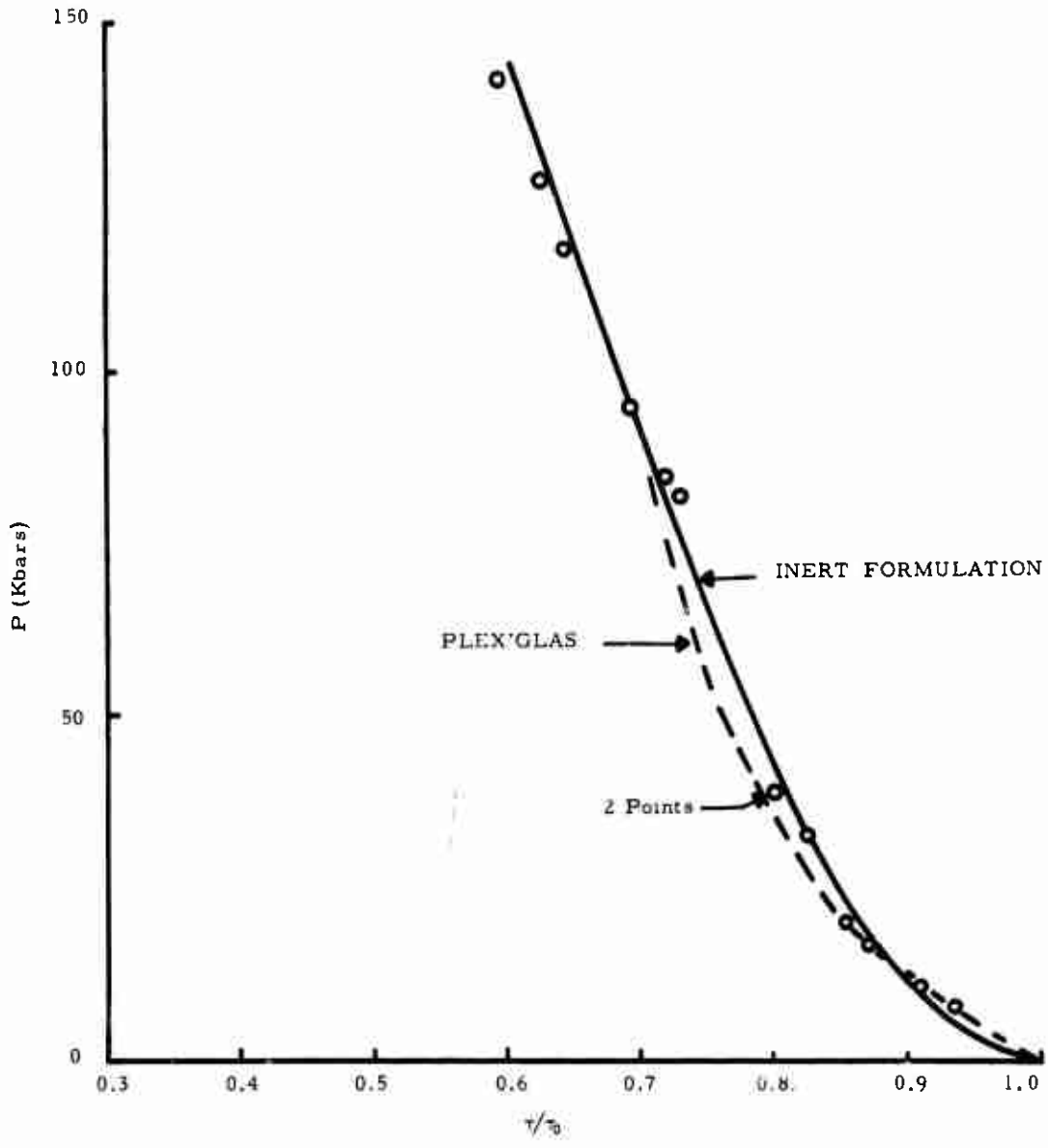

FIGURE 20. COMPARISON OF PRESSURE VS. SPECIFIC-VOLUME RATIO FOR INERT FORMULATION AND PLEXIGLAS

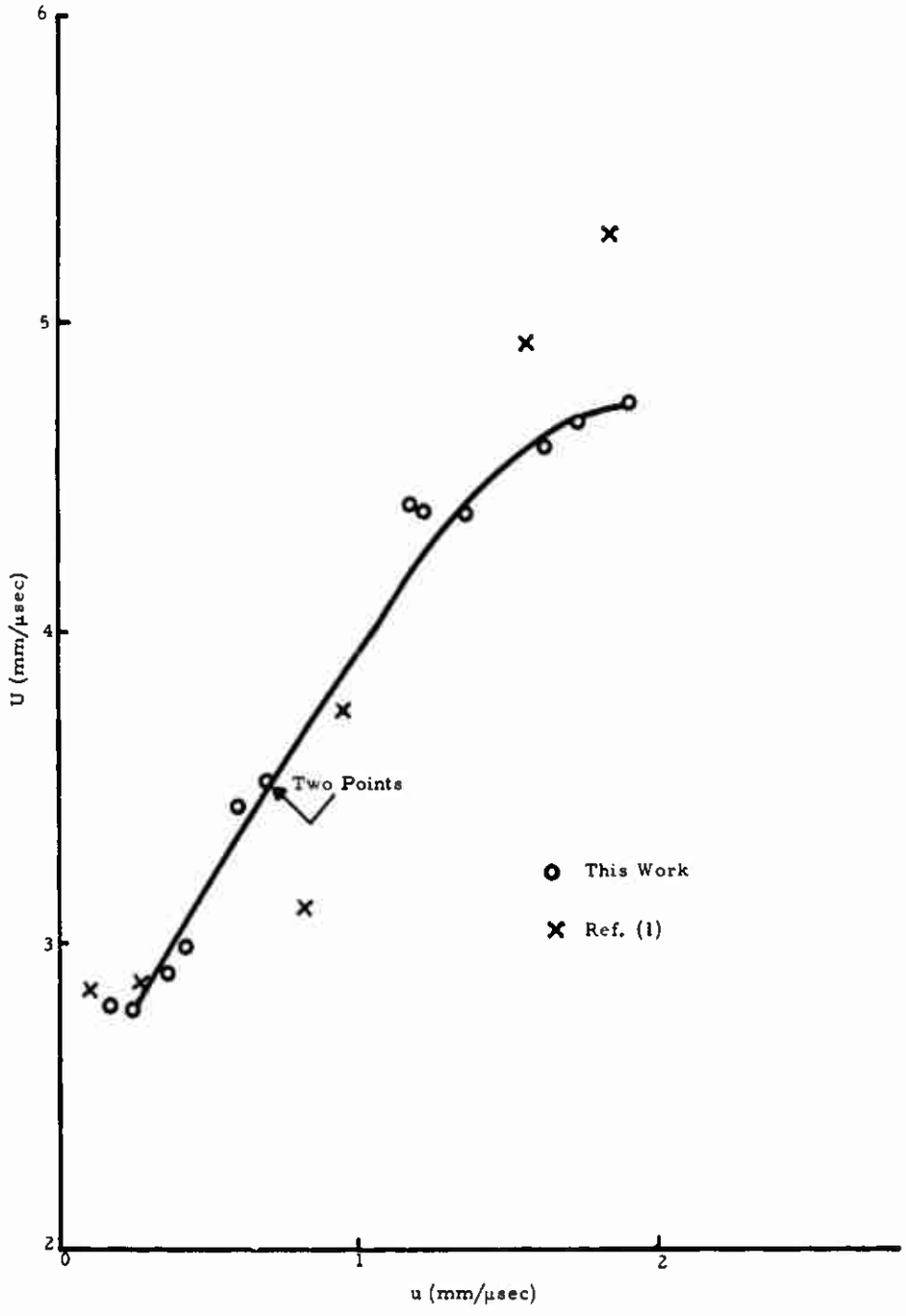

FIGURE 21. COMPARISON OF HUGONIOT DATA OBTAINED IN THIS WORK WITH THAT FROM REF. (1)

Section IV. DISCUSSION

Many different Hugoniots have been determined for Plexiglas (4). These different Hugoniots for Plexiglas will give different Hugoniots for the materials under consideration when the experimental method discussed here is used. As long as one set of Plexiglas data is used consistently the method can be used to compare different materials. The Plexiglas data chosen here (2) were obtained more recently than most of the other data, under careful experimental conditions. However, the lack of a precise knowlede of the Plexiglas Hugoniot points out the need for a different method of measurement of Hugoniots of other materials than the one reported here.

Comparison of the decay curves for the inert and active materials (Figure 8) shows definite differences. The decay of the shock velocity is slower in the active formulation. Since the only difference between the two formulations is the substitution, in the inert formulation, of a volumetric equivalent of potassium chloride for the ammonium perchlorate oxidizer of the active formulation, physical differences between the two should be small. It is postulated that the slower decay in the active formulation is caused by reaction of the ammonium perchlorate behind the shock front in a time sufficiently short that some energy is contributed to the forward motion of the front. This energy is insufficient to maintain the shock velocity at a steady value, and as the strength of the front decreases the reaction rate of the ammonium perchlorate decreases. The decay curves of the two formulations should approach each other at low shock velocities.

The shock velocity-particle velocity (Figure 10), shock velocity-pressure (Figure 11), and pressure-specific volume ratio (Figure 12) curves for the two formulations also show differences. It can be seen in these figures that the Hugoniots of the two formulations do approach one another when the shock pressure is below 10-20 kilobars or the shock velocity below about 3 mm/μsec. These results indicate that care must be used in measurement of Hugoniot data in formulations containing a reactive ingredient even in geometries where the material will not detonate. Although the active and inert formulations seem to give similar data below 10-20 kilobars this might not be true for other formulations. This point would have to be established for any given material before data obtained at low shock pressures could be used as the nonreactive Hugoniot of the material.

Although the shock velocity-particle velocity curves (Figure 19) of the inert formulation and Plexiglas are quite different, the pressure-

specific volume ratio curves (Figure 20) are quite similar. This indicates that the continuous phase in the propellant has the strongest effect in determining the response to shock waves. If anything, the propellant formulation is slightly less compressible, which is the effect expected from the addition of solids to the polymeric base.

Fiberglas appears to be slightly more compressible than Plexiglas (Figure 18). The data scatter so much in this case that no definite conclusions can be drawn.

Section V. CONCLUSIONS

While the microwave-interferometry technique is a good one for measuring shock velocities, the Hugoniot parameters derived from the data depend on the Hugoniot for Plexiglas which is not firmly established. The data obtained should be used mainly for comparing Hugoniots of different materials and not as absolute values. Development of a method which measures both shock velocity and particle velocity in the material in question would be necessary for the latter.

Reaction behind the decaying shock front in a system containing reactive components contributes energy to the front and slows its decay. A true non-reactive Hugoniot cannot be obtained from a non-detonating but reactive system except at very low shock pressures.

The continuous phase in a propellant seems to be the principal determining factor for the compressibility by shock waves. A contribution of the solids-loading is apparent in the slightly smaller compressibility of the propellant compared with unloaded polymer.

REFERENCES

1. Rohm and Haas Co., Huntsville, Alabama, SHOCK RESPONSE OF FILLED PLASTICS, E. G. Johnson and M. L. Pandow, June 1967, Report S-136, U. S. Army Missile Command, Redstone Arsenal, Alabama, Contract DA-01-021 AMC-11536(Z), (Unclassified).

2. United States Naval Ordnance Laboratory, White Oak, Maryland, RECALIBRATION OF THE STANDARD CARD GAP TEST, T. P. Liddiard, Jr. and Donna Price, 20 August 1965, NOLTR 65-43 (Unclassified).

3. Montgomery, Carol G., Ed., TECHNIQUES OF MICROWAVE MEASUREMENTS, New York, McGraw-Hill Book Company, Inc., 1st Ed. 1947, Chap. 10, 666.

4. Deal, W. E., University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, Proc. 4th Sym. on Detonation, Oct. 12-15, 1965, U. S. Naval Ordnance Laboratory, White Oak, Maryland, 321.

GLOSSARY

Symbols List

e	Specific internal energy
p	Pressure
τ	Specific volume
ρ	Density
u	Particle velocity
U	Shock velocity
s	Displacement
t	Time

Subscripts

0	Unshocked state
1	Shocked state
f	Receiving or refracting medium
i	Incident medium

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Rohm and Haas Company Redstone Research Laboratories Huntsville, Alabama 35807	2a. REPORT SECURITY CLASSIFICATION Confidential 2b. GROUP IV

3. REPORT TITLE

Hugoniot Curves of Propellants

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

E. G. Johnson and M. L. Pandow

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1967	37	4

8a. CONTRACT OR GRANT NO. DA-01-021 AMC-15414(Z) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report S-146 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Initial distribution of this report has been made in accordance with contractual agreements.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Research and Development Directorate U. S. Army Missile Command Redstone Arsenal, Alabama 35809

13. ABSTRACT

A microwave interferometry technique is used to determine shock velocities on both sides of a sample–Rohm and Haas' Plexiglas® interface. Particle velocities in the Plexiglas are determined from the known Hugoniot for Plexiglas. These particle velocities with the measured shock velocities are used in the impedance-mismatch equation to give the particle velocities in the sample. The shock pressure and specific-volume ratios in the sample are calculated for each shock velocity giving the Hugoniot parameters of the sample. Measurements were made on a propellant formulation, the same formulation with the oxidizer replaced by potassium chloride, and Owens-Corning's Fiberglas® . In the inert propellant it was found that the continuous phase (binder) has the largest influence on the pressure-specific-volume-ratio relation. The active propellant gave results considerably different from the inert propellant at pressures above 20 kbars, indicating that reaction of the oxidizer contributes energy to the shock front in a non-detonating system.

DD FORM 1 NOV 68 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hugoniot Curves						
Shock Waves						
Propellants						
Reactive Shocks						
Nonreactive Shocks						
Fiberglas®						
Shock Velocity						
Particle Velocity						
Pressure						
Specific Volume						
Microwave Interferometry						